LITTLE BLUE BOOK NO. 1000
Edited by E. Haldeman-Julius

The Wonders of Radium

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CHAPTER I

INTRODUCTORY

It has been well said that a general idea of what radioactivity signifies is a necessary part of the education of every intelligent person, since "it is the one thing of paramount importance in the chemical and physical science of the day." But its importance extends much farther, since radioactivity is now employed in many departments of industry, as well as in biology and medicine.

It is known that the rays from radium have the power to stimulate all forms of life, even to the extent of speeding up the growth of plants and of making dormant plants burst into bud. Some authorities, as we shall see later, are fully convinced that the radiations can be employed successfully in the prolongation of human life. It is well known that radiotherapy has, for some years now, been employed advantageously in the treatment of many forms of illness, and is, in some institutions, the sole medium for the cure or alleviation of cancer and other malignant growths.

Not long ago the discovery was made that the curative agent in certain famous baths in Europe is the radium which the waters of their springs contain.

If one could really buy bottled water which has been properly treated with radium rays or the "emanation," beneficial results would no doubt be obtained. The trouble is that such waters are difficult to secure.

"None of the foreign or domestic commercial bottled water sold to consumers on the claim of radioactive content really contains sufficient radioactivity to warrant its purchase," according to the report of investigation completed by the water and beverage laboratory of the United States Department of Agriculture, Washington, D. C.

"In the examination of 46 samples from 15 states and eight foreign countries, the bureau found the highest quantity of radioactivity of a temporary nature in a bottled water from Massachusetts.

"The largest amount of permanent radioactivity was in a sample from a deep well in Ohio. It was found, however, that it would be necessary to consume 2,810 gallons of the Massachusetts water, or 1,957 gallons of the Ohio water daily to obtain an efficient dose of radioactive salts.

"During the tests radioactivity of samples was determined by means of electroscopes."

When radium is taken in soluble form, 25 or 50 percent of it remains in the body for four or five days. The rate of excretion after that is only about one percent a day. "Wherever it is located, it carries on a constant bombardment in releasing its energy, giving strength to the tissues, cells and protoplasm of the body. And when once these begin to function actively, they begin to rebuild themselves."

Radium does not combine chemically with any known substance in the body. The therapeutic effects are indirect. When the electrons are ejected with great speed from the atoms of the radioactive salts, they pass through millions of other atoms, knocking out new electrons as they go, leaving the atoms with a positive charge, in which condition they are called "ions." These positively charged particles at once enter into new combinations, new chemical unions, which produce new substances. But these may be injurious to the *normal* tissues as well as to the cells of the disease which it is desired to destroy. In some cases, the diseased cells are more susceptible to the rays than are the normal cells, in which instances the growth of the abnormal or diseased cells may be retarded, or they may even be totally destroyed. It is thus seen that application of the rays may result in alleviation of the disease, or, possibly, effect a complete cure, as the case may be.

The action of radium on various (colloidal) substances is now well understood from the point of view of the biophysicist; but this phase of the subject is too highly technical for exposition in a book intended for popular circulation.

While it is fully recognized that there are quite definite limitations to the efficacy of radioactivity in its application to disease, as a matter of fact the use of radium as a therapeutic agent would be much more extensive were it not for its high cost and scarcity. No one questions its exceptional value in the treatment of certain diseases, and a method will probably be discovered, in the near future, by which it may veritably be used to postpone the age of senility.

A young man who had read somewhere that radium is a sure cure for any and all of the ills to which flesh is heir, entered a drug store and asked: "How much is radium an ounce?" The druggist smiled, and named a figure which made the young man blink. "Not really?" observed the prospective customer. "Then you may give me an ounce of cough lozenges."

Until quite recently, an ounce of radium cost almost as much as 3¾ tons of gold! That is to say, an ounce of radium, if this much could be purchased "off hand"—which it couldn't—would cost about $2,500,000. The price was at one time $3,000,000 an ounce.

When we speak of "radium," we really mean —or ought to mean—*radium salts*. Pure radium soon abandons its metallic form by entering into chemical combinations. It is the purified radium salts that cost, as late as 1923, $2,500,000 an ounce — the price of ¾ of a ton of platinum, the most "precious" of all the metals excepting radium. In 1920, radium was 200 times more valuable than an equal weight of pure blue diamonds, and 180,600 times as valuable as gold. A cubic foot of the salts—had this amount been obtainable—would have been worth $7,000,000,000.

The reason for the high cost of radium is not far to seek. First, the demand for the pure salts far exceeded the supply—and this is still the case, though relief is now in sight. Secondly, the scarcity of radium was due to the enormous amount of time and labor involved in its production.

Although radium was discovered and isolated by Mme. Curie in 1898, 22 years later—at the close of 1920—scarcely 140 grams (or about five ounces) of pure radium salts had been extracted and put on the world market. Of this amount, about 70 grams had been produced in the United States (during the preceding seven years). The market value of the standard salts was at this time about $100,000 a gram (about 1/28 ounce). Eighteen grams were produced in this country in 1920, and the value of the purified salts was quoted in some journals as $2,160,000. At this price, about $100,000 worth of radium could be put into a glass tube about the diameter of a very coarse pencil lead and not more than an inch in length.

To produce the gram of radium salts presented to Mme. Curie by the women of America (in May, 1921), 500 tons of carnotite ore—containing two percent or less of uranium oxide—were treated, consuming in the process 1,500 tons of coal, more than a ton of chemicals, and over 30 tons of water.

ALL MATTER RADIOACTIVE

While certain substances have been designated as "radioactive," it is not to be understood that these bodies alone emit charged particles, or radiant energy.

"All bodies whatever are a constant source of visible or invisible radiations, which, whether of one kind or the other, are always radiations of light" (Le Bon, "The Evolution of Forces," p. 318, 1908).

Compounds of potassium, and also of rubidium, caesium and lanthanum, as shown by Campbell, Wood, McLennan, Kennedy, and other investigators, possess very high radioactive properties. While the atomic weight of potassium is only about 39, and of rubidium about 84, the typical radioactive elements have atomic weights ranging from 200 to 238. Of the 12 to 15 elements essential to life, potassium is the only one possessing distinct if minute radioactivity. "The activity of potassium may readily be demonstrated by means of the gold-leaf electroscope. It is shown that Beta rays are emitted" (Burns). But potassium is 1000 times weaker than uranium, and 1,000,000,000 times weaker than radium, in the emission of Beta (negative) rays. Caesium and lanthanum emit Alpha (positive) rays.

Professor Dufour, the distinguished French scientist, has shown that even air that has been breathed emits radioactive particles. The presence of radioactive matter in the atmosphere has been shown to account for its electric conductivity. Thomson found (1906) that many specimens of water from deep wells contain a radioactive gas, and Elster and Gertel have found that a similar gas is contained in the soil.

It is probably safe to assert, with Le Bon, that all matter, "down to the absolute zero of temperature," radiates electrified and more or less luminous particles, albeit they are invisible to the human eye.

It is because of its property of emitting negative electrons (Beta rays) that potassium is a necessary constituent of all living matter. It may, however, be replaced, under certain conditions, by other radioactive substances.

Prof. Barton Scammel, of the British Radium Society, gave it as his opinion (in 1922) that further experience in the proper uses of potassium salts and radium in solution would lead to the realization of a new golden age. He predicted, among other "good tidings," life for 120 years in the bloom of youth, the "pep" of 25 years at 75, a third set of teeth, new hirsute coverings for erstwhile bald heads, muscles like Jack Dempsey's.

Dr. C. Everett Field, of the New York Radium Institute, stated publicly, in backing up Scammel's hopes and theories, that he thinks another ten years will see human life vastly prolonged as a matter of course by the use of radium. He said:

"We have ascertained beyond question that potassium salts are necessary to heart action, that they are slightly radioactive, and that radium can be substituted for them with a degree of success.

"It was Dr. Zwaardemaker, physiologist of the University of Utrecht, who first discovered, a number of years ago, that radium could do in the blood stream what potassium salts do in the normal person. He took an animal's heart, which was kept beating outside the animal, and removed the potassium element. It was not longer possible then to keep it in action. Then he substituted a radium solution and it was possible to restore action."

Dr. Field stated that it had been discovered that the systems of victims of cancer and other wasting diseases were deficient in potassium salts, and that as their systems were made to assimilate potassium a tonic effect was noticeable at once. The greatest trouble was to make the body assimilate the potassium.

"The fact is," said Dr. Field, one of the more conservative radium therapists, "that radium does not do the healing. But, for that matter, neither does any other form of healing. The healing exists within the organism. And radium, I am convinced, in some cases, is the most efficient medicine to give needed stimulus to the healing apparatus of diseased organisms."

Even now, he believes, radioactive treatment may prolong life at least 15 years. For internal treatment, either doses of radioactive water, or extremely minute quantities of radium itself, are administered. Radioactive water is taken from springs found to contain traces of radium, or radium is used to make ordinary water radioactive. The difficulty with spring waters is that they lose their radioactive power when bottled and transported, and must be consumed at their source.

"Because of this fact," says a writer for *The Popular Science Monthly* (June, 1923), "a group of physicians interested in the use of radium as a curative stimulant have invented an ingenious device for imparting radioactive properties to ordinary water. As designed for use in the home, this instrument consists of a case containing an arrangement of glass tubes and vessels in which emanations from radium salts in solution are imparted to air, which is then mixed with the water.

"A much simpler apparatus, available for office use, somewhat resembles a hypodermic syringe, containing special capsules of radium salts. Pushing a plunger forces air through the radium capsules and into a glass of water and is said to make the water radioactive. The doses of radium in each case are constant, because radium emanates at a constant rate, and only a certain amount can be dissolved in water, no matter how many times a day the apparatus is brought into use.

"Whether radium treatment will prove able to restore youth to old age, grow new sets of teeth and perform other marvels that its more ardent supporters predict for it, only time will tell.

"If radium treatment proves to facilitate the process of cell elimination, it will have gone a long way toward delivering the world from its enemies of disease."

The philosopher-scientist, Le Bon, makes bold to suggest that light-waves which are invisible to human eyes may be perceptible to nocturnal animals, which would include most of the lemurs and the felines, and some other beasts which seem to be capable of finding their way and carrying on their predatory or other activities in the dark. "To them," says Le Bon, "the body of a living being, whose temperature is about 37° C., or about 98° F., ought to be surrounded by a luminous halo, which the want of sensitiveness of our eyes alone prevents our discovering. There do not exist in nature, in reality, any dark bodies, but only imperfect eyes."

Le Bon has also said that the human body is sufficiently radioactive to photograph itself by its own rays, if we could find a substance sensitive to these radiations, as the photographic plate is to the actinic rays. Nothing would then be easier, he declares, than to photograph a living body in the dark without any other source of light than the invisible light which it is continually emitting.

Some recent (1924) experiments of the French scientist, Dr. Albert Nodon, seem to afford the actual proof of Le Bon's *a priori* conclusions. In the presence of a number of noted scientists, Dr. Nodon exhibited three photographic plates on which were unmistakable light impressions, which, he claimed, were caused by the rays emitted by a radioactive mineral, an insect, and a green leaf, which had been placed on the emulsion side of the plates in a dark-room.

A similar experiment, in which a dead insect and a dead leaf were used, resulted in no ray impressions on the plates. Dr. Nodon offered as his conclusion that radioactivity is an inevitable accompaniment of living processes, and stated that the strength of photographic impressions produced in experiments such as his are an accurate measure of vitality (see *Popular Science Monthly*, October, 1924).

Radium is probably present in all the planets and stars. Some time ago the Astronomer Royal of England, Dr. F. W. Dyson, demonstrated the existence of radium and of radium emanation in the sun's chromosphere (the ocean of incandescent hydrogen gas surrounding the photosphere, or actual surface of the sun).

CHAPTER II

EVERYDAY USES OF RADIUM

During the World War large quantities of radium were employed by the Allies for night compasses, luminous dials on airplanes, gun-sights, etc. In times of peace it is used on pendants for locating electric lights and switches in the dark, key-holes, fire-extinguishers, poison bottles, emergency call-bells, and in many other ways. For example, some mining corporations use signs in their mines made luminous in the dark by phosphorescent paint made from radioactive substances. These luminous signs are not affected by atmospheric conditions.

Yet for all these uses, including "radium watches" and clocks, not more than half an ounce of radium has been used since its discovery in 1898. A few millionth parts of a gram of radium, in the form of radioactive barium sulphate, a large portion of phosphorescent zinc sulphide (crystallized zinc), mixed with varnish and some adhesive substance, give enough material to illuminate 40 or 50 watches. One gram of radium (= 16 grains) combined with 20,000 grams of secret process phosphorescent zinc sulphide is sufficient to make 667,000 watches luminous for many years. The factories of this country are now turning out about four million radium watches annually.

Unless a special preparation—known only to the manufacturer—is used, the luminosity of the material gradually disappears, owing to the destruction of the zinc sulphide crystals by the powerful rays constantly bombarding them, producing flashes at the rate of 200,000 a second. The radium itself does not glow, nor does it deteriorate in power.

If we examine a luminous dial through a magnifying glass, after the eyes have been in total darkness for a few minutes, tiny flashes of light may be seen. These are caused by the explosion of hundreds of millions of radium atoms. The more radium there is in the paint, the greater the number of flashes per second, and the more durable the luminosity. Since every flash means a blow upon a crystal of zinc sulphide, the crystals gradually break under the strain. In this process helium is released from the disintegrating radium atoms.

Mr. M. A. Henry (*Scientific American*, April 2, 1921) points out that the problem of the chemist "is to produce a phophorescent substance which will stand up longest under the terrific bombardment of the radium rays and which, at the same time, will give off the most light. Such progress is being made in this direction that today [1921] only about one-twentieth the amount of radium used four years ago [1917] is needed in the making of luminous material. And the chemist insists that he has only scratched the surface of possibilities in this direction and that even better results can be attained. At present the life of the zinc crystals is from 15 to 20 years, although the radium lasts for centuries.

"This life will be much longer if the instrument to which it is applied is kept away from the light most of the time. The crystals, already stressed by the radium rays, have an additional strain imposed by the light and this hastens the process of disintegration. Strong sunlight, especially at the seashore where the presence of much ozone in the air intensifies the ultra-violet rays, has a very destructive effect on luminous material. For this reason the manufacturers of this delicate substance usually guarantee it for about half its normal life, or ten years."

A radium-lighted fish-bait is now on the market, and fishermen say that this bait is very successful in attracting fish which haunt deep water.

RADIUM MAKES GEMS BLUSH

D. Berthelot, F. Bordes, C. Doelter, and others observed that the rays from radium induced important changes in the colors of minerals.

Dr. T. Squance, of Sunderland, England, succeeded in transforming a sapphire of faint pink hue into a gorgeous ruby color, and a faint green sapphire into an oriental emerald hue. It was already known that a diamond exposed to the rays of radium glows with a beautiful green light.

In experiments carried out at the United States Bureau of Mines (1921), in Reno, Nevada, a colorless Colorado topaz was tinted yellow by exposure to penetrating radiation. If a method can be devised to make the color permanent, the discovery will greatly increase the value of the gem-stone material found in the west.

If we submit yellow phosphorous to the action of radioactive substances, it becomes changed into the red "alotropic" variety. Certain of the rays decompose ammonia, and water under their influence is subjected to electrolysis, yielding oxygen and hydrogen.

A RADIUM CLOCK

A very interesting instrument was devised by Sir William Strutt (now Lord Rayleigh) which has been called a "radium clock." It consists of a glass vessel containing a tube of radium salts in the center, from which two gold leaves are hung. The inner surface of the containing vessel is coated with tinfoil, and this foil is grounded. The radium salts cause the leaves to become electrically charged. They then diverge, and, coming in contact with the grounded tinfoil coating, they are discharged, only to fall back again and repeat the process. This clock will operate as long as the supply of radioactive material will act, which in the case of pure radium would be nearly 2000 years.

G. Lentner has recently succeeded in utilizing atmospheric potential by the aid of radioactive substances, which, in some way not yet clearly understood, exert an influence upon the transformer. The method is as follows: A post about 12 m. in height, forming a sort of antenna, is erected; the post ends in a collector consisting of an aluminum sphere provided with points covered with radioactive substances. This collector communicates by a conducting wire with a special transformer. Under these conditions the earth and atmospheric currents attract each other through reciprocal induction.

Dr. S. A. Sochoky, the well known radium expert, has made radium oil paints, and made paintings with them. "Pictures painted with radium look like any other pictures in the daytime, but at night they illuminate themselves and create an interesting and weirdly artistic effect. This paint would be particularly adaptable for pictures of moonlight or winter scenes, and I have no doubt that some day a fine artist will make a name for himself and greatly interest us by painting pictures which will be unique, and particularly beautiful at night in a dark or semi-darkened room."

Dr. Sochocky also predicts that "the time will doubtless come when you will have in your own home (or someone you know will have) a room lighted entirely by radium. It would be possible today to illuminate a room, so that at night, without the aid of electricity or other artificial illumination, you could read fine newspaper print without difficulty. The light in such a room, thrown off by radium paint on walls and ceiling, would in color and tone be like soft moonlight, blue with a tint of yellow. Today, a room ten by nine feet could be illuminated in this way at a cost of $400, and the illumination would last ten years.

"However, such illumination will soon be much cheaper, because of new discoveries as to the best materials to combine with radium to produce light."

CHAPTER III

RADIUM AND THE AGE OF THE EARTH

One of the important consequences of the discovery of radioactivity was to afford the scientist a means for solving the problem of the earth's age. By "age of the earth" we mean here the time which has elapsed since the earth's surface became fitted for the habitation of living beings. By means of radioactivity we can form an approximate estimate of the time which has passed since the formation of any given series of geological strata. Radium is our geological time clock.

It is now known that all the common rocks and soils of which the earth's crust is built up contain measurable amounts of radium. According to the computation made by Prof. John Joly, the total quantity of radioactive matter may be as much as one 500 billionth part of the whole volume of the globe, or something over half a cubic mile.

All of the 36 known radio-elements are disintegration products of the primary radio-elements uranium and thorium—*i. e.*, they are produced from one or the other of these in their long sequence of changes. And the rate at which the radioactive products change—their average life period,—from the first transmutation to the final product, radium lead, an isotrope of common lead, is accurately known.

(Helium atoms are "the debris shed at the various stages of the transformation.")

It is now well established that a gram of uranium as found along with its products in rocks and minerals is changing at a rate represented by the production of 1.88×10^{-11} grams of helium and 1.22×10^{-10} grams of lead (isotrope) *per annum*. We do not know for a certainty, of course, that this rate of production has been maintained throughout geological time. In the opinion of Lord Rayleigh, we may safely assume that the rate of transformation has not changed, so that "it would seem that in the disintegration of a gram of uranium we have a process the rate of which can be relied upon to have been the same in the past as we now observe it to be" (*Nature*, October 27, 1921).

Acting on Rutherford's suggestion, the Hon. R. J. Strutt (later Lord Rayleigh) made a determination of the amount of radium in the superficial parts of the earth—which are alone accessible; and he also determined the ratio of the lead (isotope) to the uranium, which was found to be 1.3 (specifically, in the broggerite found in the pre-Cambrian rocks at Moss, Norway). Now, if we assume—as the evidence seems to warrant—that the lead of this atomic weight (206.06) was all produced by uranium at the rate given above, we get an age of 925 million years for these rocks. Some minerals from other Archaean rocks in Norway give a rather larger figure.

"In other cases," says Lord Rayleigh, "there is some complication, owing to the fact that thorium is associated with uranium in the mineral and that it, too, produces helium and an isotrope of lead of atomic weight probably 208 exactly, about one unit higher than common lead."

Sir Ernest Rutherford estimated the time required for the accumulation of the radium content of a uranium mineral in the Glastonbury granitic gneiss of the early Cambrian as no less than 500,000,000 years. Later investigations give some of the pre-Cambrian rocks an antiquity of 1,640 millions of years! The zoologist may now have all the time he wants for the slowly evolving organisms revealed by the sedimentary strata.

Prof. John W. Gruner, of the geology department of the University of Minnesota, discovered (in 1925) microscopic forms of plant life (algae) embedded in iron formations of the Vermillion Range near Lake Armstrong, Minnesota. Most of Minnesota's iron deposits are due to the algae, Dr. Gruner thinks. The growth has the property of extracting iron from sea water and making of it a solid shell with which to surround itself. Accumulations of these iron shells through millions of years have been embedded in rock formations forming the iron ore.

Slices of rock a thousandth of an inch thick were examined under microscopes in the search for the algae. Algae began to flourish immediately after the earth, in cooling (according to one cosmological theory), got below the boiling point. Their form is much like seaweed, and they thrive at a temperature of 95° C. Dr. Gruner estimates the age of these algae-bearing deposits at 200,000,000 years, ten million years earlier than previous evidence showed.

If we employ the radioactivity test as a measure of geological time, the age of these fossil algae would have to be placed much higher—older by hundreds of millions of years. And the same must be said of the amphibian footprints recently (1925) discovered in the sandstone slabs of the Grand Canyon, by the caretaker on Hermit's Trail, a thousand feet below the rim of the canyon. On the older geological time scale, these deposits date back some 50,000,000 years (lower Carboniferous period—the so-called "Mississippian" system). On the radium time schedule, these figures would need to be multiplied considerably (according to Boltwood and Holmes, by a multiple of six or more). It should be said, however, that on the time deposits of Walcott and Schuchert, based on the rate of deposition of sediments, the lower Carboniferous (Mississippian) deposits are not older than some 18,000,000 years.

But amphibian footprints are known from the far older Devonian period, whose strata are, on the radium basis, some 370 million years old.

Prof. Charles Schuchert, of Yale, regards the estimates of geological time based upon the rate of disintegration of radioactive minerals as, on the whole, far more reliable than estimates based upon the rate of deposition of sediments. No scientist pretends to be able to state exactly the age of strata by the amount of radium lead contained in them.

"In a third class of cases," Lord Rayleigh points out, "the uranium mineral, pitchblende, occurs in a metalliferous vein, and the lead isotope produced in the mineral is diluted with common lead which entered into its original composition, . . . but the complications cannot, I think, be considered to modify the broad result.

"A determination of the amount of helium in minerals gives an alternative method of estimating geological age; but helium, unlike lead, is liable to leak away, hence the estimate gives a minimum only. I have found in this way ages which, speaking generally, are about one-third of the values which estimates of lead have given, and are, therefore, generally confirmatory, having regard to leakage of helium."

Dr. Homer P. Little, of the National Research Council, Washington, D. C., tells us (*Scientific American Monthly*, August, 1921, p. 173) that "from both calculation and experiment it is found that one gram of uranium will produce helium at the rate of one cubic centimeter in 9,600,000 years. The ratio between the amount of radium in a mineral and the amount of helium present therefore allows us to calculate the age of the mineral. The amount of uranium originally present compared to that left does not enter into the problem unless extreme lengths of time are under consideration, because of the fact that it is calculated to take 5,000 million years for one-half a given volume of uranium to disintegrate.

"It is perfectly true that much of the helium generated may escape. The assumption is, however, that in some minerals comparatively little escapes: zircon, particularly, seems to be an effective retainer. This mineral shows very effectively the increasing ratio of helium to uranium as consecutively older rocks are examined. Recent or Pleistocene specimens from Vesuvius show an apparent age of 1 million years; Miocene specimens from the Auvergne, France, of 6.3 million. The Devonian of Norway furnishes specimens 54 million years in age, and the Upper Cambrian of Colorado specimens of 141 million years; the Archaean of Ceylon, of the diamond-bearing rocks of South Africa, and of certain rocks of Ontario furnish specimens aged 286, 321 and 715 million years, respectively."

The following table gives the mean of the results of Professors Boltwood and Holmes' careful studies, based upon the accumulation of lead as a final product of the uranium series:

	MILLIONS OF YEARS
Carboniferous	340
Devonian	370
Pre-Carboniferous	410
Silurian or Ordovician.	430
Pre-Cambrian:	
Sweden	1,025
United States of America	1,310-1,435
Ceylon	1,640

These results, a total of 1,400,000,000 years, greatly transcend Lord Rayleigh's (Strutt's) earlier calculations regarding the antiquity they assign to Paleozoic and Pre-Cambrian times.

In 1918, Prof. Joseph Barrell reviewed the various methods employed and the results obtained in the attempt to determine from geological, chemical and physical evidences the time that has elapsed since the beginning of the Cambrian Period (when abundant fossil invertebrates are first met with), and reached the following time estimates for the principal divisions of the geologic record (exclusive of the Pre-Cambrian rocks):

Cenozoic time, 55,000,000 to 65,000,000 years long
Mesozoic " 135,000,000 to 180,000,000 years long
Paleozoic " 360,000,000 to 540,000,000 years long

The time thus established covers a period of from 550,000,000 to 700,000,000 years, or from ten to 15 times longer than has usually been accepted by geologists. Pre-Cambrian time was found to have a similar order of magnitude; but here the evidence rests largely upon the radioactivity of the crystalline rocks formed during this vast period.

It is now universally accepted that the time required for the formation of the Pre-Cambrian rocks was fully as long as, if not longer than, that for the succeeding geological divisions. The Archaean deposits have a vertical thickness, in the regions north of the Great Lakes, estimated at about 65,000 feet, or 12 miles. Their base, as a matter of fact, has never been reached. It is interesting to note that the granites of Norway, Canada, Texas and East Africa have an indicated age of 1,120,000,000 years, measured in terms of radium products. Prof. Henry Norris Russell, of Princeton University, concludes, from his careful investigations in radioactivity, that the age of the earth is "a moderate multiple of 1000 million years."

Professor Joly has computed that if there are two parts of radioactive material for every million million parts of other matter throughout the whole volume of the earth, and this is considerably less than he has found on the average in the earth's crust, then this earth, instead of cooling off, is actually now heating up, so that in a hundred million years the temperature of the core will have risen through 1,800 degrees centigrade.

Dr. Millikan observes (*Science*, July 9, 1921) that this is a temperature "which will melt almost all of our ordinary substances. . . . It means that a planet that seems to be dead, as this our earth seems to be, may, a few eons hence, be a luminous body, and that it may go through periods of expansion when it radiates enormously, and then of contraction when it becomes like our present earth, a body which is a heat insulator and holds in its interior the energy given off by radioactive processes, until another period of luminosity ensues."

Lord Rayleigh's series of researches for the purpose of determining the quantity of radium present in a number of representative rocks, both igneous and sedimentary, seems to prove that the average amount of radium in the earth's crust is about 20 times larger than the amount calculated by Rutherford to be necessary to retain its temperature unaltered. Joly's investigations revealed values in general agreement with these, but in many cases he obtained a value several times greater than the amount found by Lord Rayleigh. Further investigations showed that thorium is as widely distributed as radium in the earth's crust, which is true also of uranium.

"Incredible as it may appear," remarks Rutherford, "the radioactive bodies must have been steadily radiating energy since the time of their formation in the earth's crust. While the activity of uranium itself must decrease with the lapse of time, the variation is so slow that an interval measured by millions of years would be required to show any detectible change."

In his 1921 address to the British Association for the Advancement of Science, Lord Rayleigh said: "It appears certain that the radioactive materials present in the earth are generating at least as much heat as is now leaking out from the earth into space. If they are generating more than this (and there is evidence to suggest that they are), the temperature must, according to all received views, be rising."

CHAPTER IV

AN EPOCH-MAKING DISCOVERY

When radium was discovered by Mme. Curie in 1898, the effect upon the scientific world was startling, not to say "catastrophic"—as one author wrote at the time—since its activities ran counter to every known principle of physical science. "Some of the most solid foundations of science were destroyed, some of its noblest edifices wrecked, and scientists had to nerve themselves to face and investigate a new form of energy."

So soon as radium compounds (salts) became available, however, the amount of energy given out in radioactive processes—the emission of powerful radiations which can be transformed into light and heat—was measured; and it was found that radium, weight for weight, gives out as much heat as any known fuel every three days, and in the course of fifteen years releases a quantity of energy nearly 2,000 times as much as is obtained from the best fuel, with no signs of exhaustion (Soddy). In the combustion of coal, the heat evolved is sufficient to raise a weight of water some 80 to 100 times the weight of the fuel from the freezing-point to the boiling-point. The spontaneous heat from radium is sufficient to heat a quantity of water equal to the weight of radium from the freezing-point to the boiling-point every three-quarters of an hour. In other words, a pound of radium contains and evolves in its changes the same amount of energy as 100 tons or more of coal evolve in their combustion.

In ordinary chemical changes it is the *molecules* (groups of atoms) which are altered or rearranged; in radioactive change the atoms themselves suffer disintegration and rearrangements. The energy of radioactivity, then, is—according to the accepted view—intra-atomic—stored-up energy within the atom itself. It was calculated by Prof. Curie that the energy of one gram of radium would suffice to lift a weight of 500 tons to a height of one mile. If it were possible to obtain one cubic centimeter (a thimbleful) of the "emanation" from radium in the form of a gas, we should find that it possessed the power, altogether, of emitting more than seven million calories of heat! A thimbleful of this invisible gas would be more than sufficient to raise 15,000 pounds of water 1°. But in every mass of radium, small or large, not more than 13 trillionths of it is undergoing change per second.

"The processes occurring in the radio-elements," says Rutherford again, "are of a character quite distinct from any previously observed in chemistry. Although it has been shown that the radioactivity is due to the spontaneous and continuous production of new types of active matter, the laws which control this production are different from the laws of ordinary chemical reactions. It has not been found possible in any way to alter either the rate at which the matter is produced or its rate of change when produced. Temperature, which is such an important factor in altering the rate of chemical reactions, is, in these cases, entirely without influence. In addition, no ordinary chemical change is known which is accompanied by the expulsion of charged atoms with great velocity. . . . Besides their high atomic weights, [they] do not possess in common any special chemical characteristics which differentiate them from the other elements."

It was early observed by Curie and Laborde that the temperature of a radium salt is always a degree or two above that of the atmosphere, and they estimated that a gram of pure radium would emit about 100 gram-calories per hour. Giesel later showed that radium was always at a temperature 5° higher than the surrounding air, regardless of what the temperature of the air might be. This continues unchanged whether the temperature of the surroundings be 250° below zero Centigrade, or in the intense heat of an electric furnace.

"Perhaps," remarks a writer in *The Scientific American* (February, 1922), "there will come a time when we shall use the energy in the atoms to drive our machines, cook our food and heat our rooms. Besides, already today we are actually using—even if only a very tiny part—the atomic energy. Thus, for instance, the rays emanating from radium are used for therapeutic purposes and the electrons emanating from a glowing filament can be directed so easily that they can be used in a large number of apparatus for wireless telegraphy and telephony. Most probably plants also make use of this energy in their growth because it has been demonstrated that the rays of the sun liberate electrons from the green leaves, and lastly it may also be mentioned that we humans use a little of this intra-atomic energy when seeing with our eyes, which we are enabled to do by the photoelectric action of light."*

During the course of the process of disintegration, atoms of uranium and thorium and their products give rise to no fewer than 36 different substances (A. S. Russell), and of these at least a dozen are "new elements."

All of the 36 radioactive elements are disintegration products of one or the other of the two parent elements, uranium and thorium. They are arranged by the chemist in three series: namely, Uranium 1, Uranium 2 (the Actinium Series), and Thorium. In the first series there are known to be 15 transmutations of matter; in the second, 11; and in the third, 10. The periods of "half change"—the period required for one-half of a given quantity of a radioactive element to decompose—of the different radioactive elements vary all the way from thousands of millions of years for the longest lived primary elements—2.6×10^{10} years for thorium, 8×10^{9} for uranium 1—to .002 second for actinium A. In the case of radium itself, 1,670 years are demanded for the disintegration of half of any portion, according to the exact measurements of Profs. B. O. Boltwood and Ellen Gleditsch. The stable end product appears to be in each case an *isotope* of lead—

*See Shipley, Maynard, "Electricity and Life," ch. vi., Little Blue Book No. 722.

leads having similar chemical properties but of different *atomic weights* (*i.e.*, different atomic composition).

Isotopes are groups of elements which cannot be distinguished (or separated from) one another by any known chemical methods, and which differ only in the atomic weights of the members of the group. In the radioactive groups, the various elements differ also in degree of stability of their atoms.

Chemists cannot actually weigh the mass of an atom of an element on a pair of scales, or by any other method. But if we put down 16 as the "atomic weight" of oxygen, and ascertain the "combining weight" (ratio) of hydrogen to oxygen, we can determine the "atomic weight" of hydrogen (1.008). (See Shipley, "The A B C of the Electron Theory of Matter," p. 14, Little Blue Book, No. 603.) The ratio of the masses of *any* two elements in a chemical compound can be very accurately determined. Without going into the details here, it may be said that the *relative* weights of the atoms of any element can be determined to 0.01% in many cases (by chemical analysis and synthesis); while the *actual* weight of any atom has not yet been determined to better than 0.1%.

HOW RADIUM IS CONVERTED TO LEAD

Lead is produced from uranium by a successive series of losses of Alpha particles—or helium atoms. Omitting the less essential outcomes, or transition stages, we find that each atom of uranium spontaneously ejects three atoms of another element, helium, and thereby is converted into still another element, radium. By losing one atom of helium, radium, in turn, is converted into the so-called emanation, or *niton*. The latter quickly loses four more atoms of helium and is converted into lead, "uranium lead," having an atomic weight of 206.08. Ordinary (common) lead, constituting the vast bulk of the lead of the world, has a much higher atomic weight, namely, 207 (Prof. Theodore Richards). Lead from thorium has an atomic weight of 208; from actinium, 206. So we have, in fact, four kinds of lead.

Omitting the less stable transition products, we may say, then, that an atom of uranium is converted into lead by the loss of eight atoms of helium—losing three to become radium, then one to become the emanation, and finally four to become lead. No known human agency can either retard or hasten this breaking down of the uranium atom into radium, or of the radium into emanation, with the final production of lead.

This statement has been universally accepted as true. Nevertheless, Dr. A. Glaschler stated (*Nature* [London], September 12, 1925) that he had succeeded in accelerating the change of uranium to uranium X (the first product of uranium 1) by submitting uranium oxide to "strong rushes of momentary high-tension currents." As early as 1923, A. Nodon (*Comp. rend.*, *176*, 1705 [1923]) brought forward strong evidence of an increase of the activity of radioactive substances when outdoors and enclosed by envelopes of small absorbing power for Gamma rays as contrasted to the smaller radioactivity of the same substances in cellars and when heavily enveloped by lead. For a tentative explanation of this phenomenon, see *Science*, January 8, 1926 (Vol. LXIII, No. 1619), pp. 44-45.

Both uranium and thorium, as we have just stated, break down and become radium, then change to helium and lead.

Says Rutherford: "Although thorium is nearly always present in old uranium minerals and uranium in thorium minerals, there does not appear to be any radioactive connection between these two elements. Uranium and thorium are to be regarded as two distinct radioactive elements.

"With regard to actinium, there is still no definite information of its place in the scheme of transformations. Boltwood has shown that the amount of actinium in uranium minerals is proportional to the amount of uranium. This indicates that actinium, like radium, is in genetic connection with uranium. . . ."

The recently discovered product, *protoactinium*, — isolated by Hahn and Soddy, — is the hitherto missing link between uranium Y and actinium. "This substance emits Alpha rays and has an estimated period of 10,000 years. The actinium series is believed to have its origin in a dual transformation of uranium X. The first branch product, representing about 4% of the total, is believed to be uranium Y, a Beta-ray product of period one day. This is directly transformed into protoactinium." This element has not yet been obtained in a pure state.

Many of the radioactive elements are isotropic with known chemical elements—*i. e.*, alike in their chemical properties, but dissimilar in radioactive properties. Since they cannot be distinguished—or separated—from the ordinary elements with which they are isotropic, by any chemical methods, they must occupy the same place in the periodic classification of the elements. Radium and mesothorium, for example (as Soddy was first to show) do not have the same atomic weight, but they cannot be distinguished from each other by any chemical methods. Therefore they both have the atomic *number* 88, though the atomic *weight* of radium is 226 and of mesothorium 228. (See Shipley, "Origin and Development of the Atomic Theory," p. 64, Little Blue Book, No. 608.) Radium D and lead, and thorium and ionium, are examples of radioactive isotropes.

The nature of the end-product was first suggested by Boltwood, who pointed out the invariable presence of lead in old radium minerals, and in amount to be expected from their uranium content and geologic age. "Thus," says Prof. T. W. Richards, of Harvard University, "we must adopt a kind of limited transmutation of the elements," although not of the immediately profitable type [gold] sought by the ancient alchemists."

Sir Ernest Rutherford, who succeeded Sir J. J. Thomson as Cavendish Professor of Physics at Cambridge University, was first to recognize that the rays from uranium and radium were not all alike, but consisted of three distinct kinds. In order to distinguish them clearly, without committing himself in advance as to their exact nature, he christened them Alpha, Beta, and Gamma rays—the first three letters of the Greek alphabet. We know now that the Alpha rays are positively charged helium atoms, with two negative electrons missing; that the Beta rays are negatively charged electrons (disembodied "particles" of electricity, exactly like cathode rays); and that the Gamma rays are a type of X-rays, not material particles but merely extremely short magnetic waves or oscillations, akin to ordinary light waves or rays.

Dr. R. A. Millikan calls them "the wireless waves of the denizens of the sub-atomic world. They are ether waves, just like light or just like wireless waves, except that the vibration frquency . . . amounts to 30 billion billions per second. These are the Gamma rays." This means that this number of light waves would pass a given point in space each second. Since these rays do not consist of charged particles they are not deflected by electromagnetic or electrostatic fields, as are the Alpha and Beta rays. It has been found that one gram of radium ejects 136,000,000,000 particles a second!

The Gamma rays of radium have such penetrating power that a half-inch sheet of lead will reduce their original intensity by only one-half, and they are not absolutely stopped by 20 inches. These invisible light waves, thousands of times shorter than those of visible light, are produced whenever a cathode ray (negative electron) hits matter. Of the atoms forming the substance penetrated, perhaps only one in a billion is struck. It has been said that the Gamma rays (and X-rays) are the result of the back-kick of ejected electrons. Prof. Comstock says that the connection between the Beta rays and the Gamma rays "is probably similar to that between the bullet and the sound in the case of a gun." However this may be, we know that the Gamma rays are, after all, in essence only excessively minute light waves. While the longest visible light waves are 0.00008 centimeter, the longest Gamma rays are 0.000000013 centimeter; and whereas the shortest visible light waves are 0.00004 centimeter, the shortest Gamma rays are but 0.0000000007 centimeter.

The Beta particles are ejected with a velocity of from 90,000 to 160,000 miles a second.

Prof. Gustave Le Bon calculated that it would require 340,000 barrels of powder to discharge one bullet at this inconceivable speed! These negatively charged electrons normally revolve around the positively charged nucleus. Under certain conditions, an electron will make 2200 billion revolutions within an atom in one second.

Radium is not only continually losing matter and energy as electricity, but it is also losing energy as heat. Professor and Mme. Curie discovered that any substance placed near radium becomes itself a *false* radium. This applies to all substances. The acquired radioactivity persists for many hours, or even days, after the removal of the radium. In the case of zinc, these secondary radiations were found to be four times as intense as ordinary uranium. It vanishes sooner or later upon the removal from the neighborhood of the potent radium.

The radioactive something which passes out of radium was not the already known group of Alpha, Beta and Gamma rays, but an *emanation* akin to gas. Rutherford, its original discoverer, was not sure that it was a gas, so he cautiously gave it the name *emanation*. When the radium was heated, or dissolved in water, the quantity of emanation was greatly increased, which seemed to show that it was a gas of some kind occluded (bound up) in the radium. The quantity obtained was insufficient to bring the emanation within the testing power of spectroscope or balance.

Nevertheless, the emanation has been detected, and investigated by the electroscope, which measures the radium rays by the power to discharge its electrified gold leaves. "The electroscope is about a million times more sensitive than the most sensitive spectroscope and yet the spectroscope is capable of detecting easily the millionth part of a milligram of matter" (Duncan).

Calculations made by Rutherford show that if a thimbleful of this active gas could be collected, the bombardment of its powerful rays would heat to a red heat, or even might melt down, the walls of the glass containing it. The emanation emits only Alpha rays (or particles) forming helium.

The radium from which the emanation has been abstracted, after the lapse of an hour or so, loses 75% of its activity. During the course of a single month, radium will be found to have restored all its lost emanation. In thirty days it will have regained all its original activity. It was soon discovered that the emanation abstracted from the radium loses its radioactivity at the same rate and according to the same laws as the de-emanated radium regains it. The radium is therefore said to be "in equilibrium with its products."

Since these processes are wholly outside the sphere of known controllable forces, and cannot be created, altered or destroyed—"since the process is independent of the chemical form of the radium, whether bromide, chloride, sulphate, etc., we are absolutely shut up to the conviction that it is a function of the atom. We are in the presence of an actual decay of the atom. The atom of radium breaks down into atoms of emanation and the atoms of emanation in their turn break down into something else. The activity of emanation decays and falls to half value in about 3.7 days."

Although the amount of emanation produced from a gram of radium does not amount to more than a needle-point of the gas (= 1.3 cubic millimeter), this is sufficient to raise the temperature of 75 grams of water 1° per hour, which is enough heat to melt *more than its own weight* of ice in an hour, and to raise it to the boiling-point in the next hour, which is equivalent to 60,000 horse-power days! In other words, the heat evolved by the radium emanation is more than 3,500,000 times greater than that produced in any known chemical reaction: such as, for example, the union of oxygen and hydrogen to form water.

It was soon discovered that if the spectrum of this mysterious gas—or radium emanation —be examined again after an interval of about four weeks, it has changed into a familiar spectrum easily recognized as that of the gaseous element known as helium. Here the chemist comes face to face with the astounding fact that the element radium is decomposed and produces another element, helium—a discovery made by Ramsay and Soddy in the summer of 1903.

In the successive radioactive changes, one Alpha particle (sometimes called "ray") is ejected from each atom disintegrated by the change—in some cases, at least, accompanied by Beta particles (negative electrons). The Alpha particle, as already stated, is really an atom of helium carrying two atomic charges of positive electricity—twice that of an atom of hydrogen. Strictly speaking, the Alpha particle is only the *nucleus* of a helium atom, since it has lost two of its negatively charged electrons, which are combined in the ordinary helium atom. The exact velocity of the expelled Alpha particle "varies in the different radioactive elements" (Joly)—say from 10,000 to 18,000 miles each second—a velocity sufficient to carry the particle around the earth in less than two seconds, if unchecked.

But these relatively heavy particles (of atomic size) are actually soon checked, even by seven centimeters (about a third of a foot) of air. The Beta particle (1,845 the mass of a hydrogen atom) "shoots a hundred times as far [as the Alpha particle] and the Gamma rays are a hundred times more penetrating still" (Millikan). But the Alpha particle is sometimes ejected with a velocity nearly 40,000 times that of a rifle bullet,—the velocity of the latter being about half a mile a second. Even the super-guns which bombarded Paris could not eject a projectile with a speed of more than about a mile a second. Rutherford observes that if it were possible to give an equal velocity to an iron cannon ball, the heat generated on a target would be many thousand times more than sufficient to melt the cannon ball and dissipate it into vapor.

The flashes of light seen when the Alpha rays bombard a screen of zinc sulphide, as in Crookes' spinthariscope, are due to cleavages produced in the zinc sulphide crystals by the impact of the Alpha rays (positive ions). Each impact on a crystal produces a splash of light big enough to be seen by a microscope.

In the phosphorescence caused by the approach of an emanation of radium to zinc sulphate, the atoms throw off the Alpha (helium) particles to the number of five billion each second, with velocities of 10,000 miles or more a second. If the helium projectile should chance to "crash" into an atom of nitrogen or of oxygen, an atom of hydrogen can be knocked out of it, as was discovered by Sir Ernest Rutherford, perhaps the most distinguished of Mme. Curie's pupils. (Strictly speaking, the disintegration particles are isotropes of helium, of atomic weight 3, the atomic weight of helium being 4.) Despite its large size as compared with an electron (or Beta particle), the Alpha particle passes through a glass wall without leaving a hole behind, and without in any way interfering with the molecules of the glass. It shoots through hundreds of thousands of atoms without ever going near enough to them to be deflected from its course.

CHAPTER V

RADIUM IN THE TREATMENT OF CANCER

The action of radium on human tissues was unknown until 1896, when Prof. Henri Becquerel of Paris, having incautiously carried a lump of pitchblende in his pocket, discovered on his skin, within two weeks, a severe inflammation, or ulcer, which was known as the famous "Becquerel burn." As physicians of the nineteenth century were accustomed to burn out cancers with caustics, the idea occurred to them that the application of radium might prove to be an improvement on the older method.

It has proved to be so, affording in many cases not only relief, but in some instances, even a cure, not only for cancer, but for many other ailments—as we shall see presently. Since that time active investigation into the action of radium on diseased tissues has been carried on, resulting in the establishment in Paris of the "*Laboratoire biologique du Radium*," and also of the Radium Institute of Vienna, followed by the establishment of somewhat similar institutions in various other countries, notably in England and the United States.

One of the most famous institutions for radiotherapy is the recently established Radium Institute of Paris, under the management of Mme. Curie and Professor Debierne. This is composed of two distinct compartments. In one the scientific properties of radium are studied, while the other is devoted to its therapeutic applications. Dr. Regaud, who is in charge of the latter department (a branch of the widely known Pasteur Institute), endeavors to cure cancer and tumors by application of radium and X-rays.

New York City boasts a magnificently equipped Radium Institute, under the directorship of Dr. C. Everett Field. And an even more famous institution is that founded by the Mayo brothers, in Rochester, Minnesota, where these eminent surgeons had accumulated an entire gram of radium as early, at least, as 1920—the largest amount owned by private individuals. This great institution—now known as the Mayo Foundation—is no longer privately owned, but it is still under the direction of the Mayos.

Radiotherapy (or, in France, *curietherapy*, in honor of the discoverer of radium) or the treatment of various diseases by radioactive substances, has not been applied so extensively as has treatment by X-rays (Roentgen rays), produced in vacuum tubes. On the other hand, the X-rays are not so effective (as usually applied) in the treatment of certain morbid conditions as are the more penetrating Gamma rays from radioactive substances; though the latter are essentially identical with X-rays—swift Beta particles, or negative electrons—of very short wave-length. To produce X-rays as penetrating as the Gamma rays, about two million volts would have to be "cut" on the discharge tube.

The Alpha rays are not often used in medical practice, and have little penetrating power. They are stopped by 3½ cm. of air, or by a thin sheet of paper. They are employed only in the way of radium "emanation" (a gas) dissolved in saline solution, or by the use of needles upon which active deposit from radium emanation has been collected. "In either case the emanation water or the active deposit needles must be introduced into the system—whether intravenously or into the solid tissues, —otherwise the Alpha rays would have no power to act. In either case, too, they act along with the Beta and Gamma rays produced by the active deposit" (Lozarus-Barlow).

Beta radiation is used only for superficial conditions and always in conjunction with Gamma radiation. "Instead of a radium salt, one of its products, viz., radium emanation, is often employed chemically. No essential difference is introduced by the use of this emanation excepting that its intensity undergoes a progressive diminution with time, since it falls to half value in 3.85 days. Early rodent cancer, certain conditions of the eyelids, some cutaneous non-malignant tumors and birth-marks, are treated successfully in this way."

Physicians of the Memorial Hospital, New York City, announced in October, 1925, that by filtering out 90% of the caustic Beta rays emanating from radium and the high voltage X-ray tube, and using principally the healing and stimulating Gamma rays, radiation treatment of cancer of the tongue, lips, nose, ears or other part of the head has been greatly improved.

In the first six months after the new method was begun, more than 100 cases had been treated with what were considered very satisfactory results. Owing to the elimination of the caustic rays, much stronger applications of the beneficial rays can be used, and painful effects are largely obviated.

If experience and special research lead eventually to successful treatment of cancer, it will be a great boon to the human race. The United States leads the world in deaths from this dread disease, with its average of 90 per 100,000 of the population. The mean average of cancer deaths in Europe is 76, in Asia 54, in Africa 33, in Oceania 73. Several races, including the American Indians, are stated to be entirely free from cancer, and others are partially immune. The Japanese, for example, are subject to all forms except cancer of the breast. Eighty-five percent of Americans afflicted with this malady are persons over 40 years of age.

Science Service states that a careful analysis of cancer statistics gathered by the United States Census Bureau over a period of about 20 years in ten Eastern states reveals definitely that cancer mortality is from 25 to 30% higher than it was about 20 years ago. This is the claim of Dr. J. W. Schereschewsky, of the United States Public Health Service, who made the statistical analysis and reported it to the American Medical Association. "There has been a pronounced increase in the observed death rate from cancer in persons 40 years old and over in the ten states comprising the original death registration area," Dr. Schereschewsky said. "Part of this increase is due to greater precision and accuracy in the filling out of death returns, but the remainder is an actual increase in the mortality of the disease."

The only way to stop the ravages of cancer, says the Paris Academy of Medicine, is to diagnose it early—in time for operation. For this to be practicable, physicians must be specially instructed. Family doctors are often ignorant of all but a few forms of cancer and do not recognize it in its first manifestations. Women of 40 to 50 are apt to consider little irregularities of bleeding to be associated with the menopause and therefore harmless. Often this is right, but unfortunately the bleeding from an early cancer may not differ in the slightest degree from such harmless irregularities and by the time other symptoms have developed, the cancer has perhaps grown through the wall of the uterus and has spread to regions where no treatment can hope to reach it. The only safe rule to go by is to seek expert investigation for any unusual or irregular bleeding or discharge, however slight, especially if these occur at or near the "change of life."

One phase of this subject of special interest is that of the use of radium in the treatment of cancer, especially of the neck or lower end of the uterus. There is already sufficient evidence to warrant the statement that some cancers of this region have been permanently cured by radium alone. And as a relief measure in the late and hopeless stages of the disease, radium prolongs life, relieves pain and adds much to the comfort of the victim.

It has been amply demonstrated that radium treatment increases the permanency of the results obtained by surgery, and often converts inoperable into operable cases.

CHAPTER VI

EFFICIENCY OF RADIUM IN TREATMENT OF VARIOUS DISEASES

In 1923, Dr. R. E. Loucks, president of the American Radium Society, announced that toxic goiter had been cured by radium. Exophthalmic goiter has been, in most cases, successfully treated by irradiation. Just how the cure is effected is still unknown; for the thyroid body from animals exposed for many hours to the Gamma irradiations of radium bromide shows no perceptible histological changes. Yet far less radiation produces marked changes in the tadpoles derived from normal ova fertilized by spermatazoa which have been radiated in the frog, though no testicular changes can be detected with certainty (Encyclopaedia Britannica, Vol. 32, p. 224, 12th Ed.).

Among other diseases which have been more or less successfully treated by radium may be mentioned lupus vulgarus, epithelial tumors, syphilitic ulcers, chronic itching of the skin, papillomata (an epithelial tumor formed by hypertrophy of the papillae of the skin or mucuous membrane, as a corn or a wart), angiomata (tumor composed chiefly of dilated blood or lymph vessels), pigmentary naevi (blemish of the skin due to pigment, as a birthmark), and pruritus (itching). Radium has been particularly effective in treating serious affections of the eyes, as was first fully demonstrated by Dr. Walter S. Franklin and Frederick C. Cordes, of San Francisco.

The most brilliant successes of radium have been in those cases "where some serious complicating ailment, such as heart disease, tuberculosis, Bright's disease, or an extreme anemia, contra-indicates anesthesia or any procedure which will tax the patient's vital resources; radium steps in and does its work quietly, imperceptibly and, indeed, without the slightest risk to life."

Dr. Howard A. Kelly, of Johns Hopkins University, has been very successful in curing swollen masses of glands on the sides of the neck, cancer of the thyroid and of the cervix, and sarcoma of the chest. Dr. E. S. Molyneaux of London, has cured obdurate cases of tubercular glands in the neck, a disease rather frequent among children. Thanks to the patient researches of Dr. John A. Marshall, associate professor of biochemistry and dental pathology at the University of California, it is now known that a radioactive liquid may be used for sterilizing infected tissue. Experiments employing the radioactive liquid in the treatment of root canals have been conducted at the George Williams Hooper Foundation for Medical Research and at the College of Dentistry of the University of California.

Within the time that the new antiseptic has been in use at these colleges, 85% of all the cases treated have been successful; and, with one exception, no soreness or pain has followed its use. This radioactive preparation is a solution of radium salts, "Radium D plus E," which results from the decomposition of radium emanation, which, readily soluble in water, possesses definite radioactive properties. In making the solution the tiny capillary tubes containing the decomposed radium are crushed under water in a mortar and the liquid is then ready for use in the treatment of an ulcerated root of a tooth.

Dr. Marshall had been working with radium for months before admitting the success of his investigations, which were conducted in a long series of experiments on the lower animals. "Microscopic examinations of abscessed tissue," he said, "which have been treated with radioactive solutions, indicate that the bacteria producing the affection were killed. And in no cases observed has the treatment produced radium burns; the amounts used have been too small and the effects of too transitory a nature. That sterilization of tissue can be produced, however, seems apparent.

"The discovery is purely of academic interest because of the fact that radium is too expensive, and it is possible to obtain it only in limited quantities; so that the chief value of the discovery will rest in the fact that it will stimulate further work for the identification of more accessible material."

In external treatment by radium itself, emanations from a certain quantity of radium are allowed to focus on parts of the body over the diseased organs. Thus the curative functions of the diseased portion are stimulated to activity. The atrophying of diseased tonsils has been the most successful use of tihs form of treatment.

In the destruction of disease germs the radium emanation has been found more useful than the direct rays. The emanations kill or check the growth of anthrax, typhoid, and diphtheric germs. The direct rays are efficient in the relief of severe cases of enurites and facial neuralgia, cancer, tumors, affections of the skin and abnormal growths. Dr. Guyenot has proved that radium effects a complete cure for rheumatism, which he accounts for in these words: "Uric acid circulates in the blood in the form of urate of soda, of which there are two isomeric forms differing from each other by their respective solubility in the blood plasms. The soluble salt is converted into an insoluble form." Radium breaks up this compound. The "rheumatism" disappears.

CHAPTER VII

WHERE WE GET RADIUM

The extraction process consists in eliminating the various substances in the ore until only the radium salts are left. But, in the case of carnotite, more than 900 different operations, requiring six months of labor, are required between the digging of the ore and the production of a gram of pure radium salt. A solution containing barium and radium salts in the ratio of ten parts of radium to a billion is treated with sulphate to precipitate an insoluble "raw sulphate of barium."

Radium ores are generally found in connection with granitic masses—i. e., in places where granite forms at least part of the rock of the country. The carnotite ore usually consists of a thin layer of sandstone which crops out on the side of a canyon wall and is recognized by the characteristic sulphur-yellow color. The narrow seams are usually in the form of pockets, so that the value of a claim is dubious until it has been thoroughly explored and worked.

Most of the original radium minerals, such as uraninite, samarskite, and brannerite, are black and have a shiny fracture and a high specific gravity. These minerals are, however, rarely found in commercially valuable quantities.

Pitchblende, the richest source of radium, has the same composition as uraninite and the same general appearance, except that it shows no crystal form. It occurs in veins. There are extensive deposits of pitchblende or uraninite at Joachimstahl, Bohemia (Czecho-Slovakia), containing from 30 to 70 per cent uranium oxide, from which the radium is extracted. But here the uranium ore occurs in small pockets in widely separated localities, so that it is merely a by-product of other mining operations. However, after separation of the uranium from the ore, the residues are three to five times as radioactive, weight for weight, as the uranium. The amount of radium in old unaltered mineral is always proportional to its content of uranium in the ratio of 3.3 parts of radium by weight to ten million parts of uranium.

New radium ore fields were discovered in Czecho-Slovakia in 1922. The production of radium in that country increased from .7746 gram in 1911, to 1.7118 grams in 1915, and 2.2310 grams in 1920. In 1922, steps were taken to modernize the plants in the Jachcymov district (Bohemia), where the known supply will last 20 years at the present rate of production —a little more than two grams a year.

The famous Joachimstahl pitchblende deposits were a monopoly of the Austrian Government before the World War, but they are now being worked by the Imperial and Foreign Corporation of London, under an agreement with the Czecho-Slovak Government. In 1922 a loan of two grams of radium (valued at more than $300,000) was made to Oxford University, for a period of fifteen years. This material is being used for experimental purposes by Prof. Frederick Soddy, of Oxford, and his associates. It has been stated that one of the chief objectives is the discovery of a method for the release and control of intra-atomic energy.

Pitchblende has been found in only a few places—in Bohemia (Czecho-Slovakia), southern Saxony, Cornwall, and Gilpin County, Colorado. So far, this ore has not been the source of any radium produced in this country.

When the original radium minerals (uraninite, samarskite, brannerite, etc.) break down through weathering, other radium minerals are formed from them, such as autunite, trobernite, carnotite, and tyuyamunite. The two latter ores are the most widespread and abundant. Autunite, a phosphate of calcium and uranium, is as active as uranium. Carnotite and tyuyamunite cannot be distinguished visually from each other. Both are a bright canary-yellow in color, and are powdery, finely crystalline, or, rarely, clay-like in texture. Both these minerals are found in the same section of Utah and of Colorado, usually associated with fossil wood and other vegetation, in friable, porous, fine-grained sandstone.

The only other deposits that yield tyuyamunite in marked quantity are those of Tyua-Muyun, in the Andiyan district, Ferghana Government, central Asiatic Russia (Russian Turkestan), where it occurs with rich copper ores in a pipe in limestone.

The radium salts—hydrous sulphate, chloride, or bromide—are all white or nearly white substances, no more remarkable in appearance than common salt. Neither radium nor the radium minerals are in themselves luminescent. Tubes containing radium salts glow because they include impurities which the invisible radiations from the radium cause to give light. The pure radium metal has been isolated only two or three times, and few persons have seen it.

NEW SOURCES OF RADIUM

In 1921, a rich deposit of pitchblende was discovered in the province of Ontario, Canada. Since 1921 there has been a rather considerable exportation of radio-active minerals from Madagascar; and in 1922 deposits of uranium oxide (U_3O_8) were discovered in Switzerland. During the same year an unknown Belgian traveler sold to a curio dealer a strange stone picked up in the Congo. The dealer sold it to the British Museum. Upon examination the stone was found to be radioactive. Belgian geologists were immediately informed, and a Belgian mission was sent to the Katanga district, where the stone was found. Two veins of chalcolite (torbernite) containing substances rich in radium were soon located by the geologists, one near the Portuguese frontier. Chalcolite, the crystallized phosphate of copper and uranium, is twice as active as uranium.

The newly discovered mineral has been given the name "curite," in honor of Mme. Curie, the discoverer of radium. These deposits are now known to be the richest in the world. And, what is hardly less important, the radium may be isolated by simple dissolution in nitric acid, even in the cold. It is also readily dissolved in warm hydrochloric acid. Only 15 tons of the ore need to be treated to produce a gram of radium.

Curite is found in three forms, as translucent reddish brown needle-like crystals; as compact saccharoid crystalline aggregates, orange in color; and as orange-colored earthy masses surrounding the preceding variety. The chemical composition is expressed by the formula $2(Pbo)5(UO_3)4(H_2O)$.

In 1924 a pitchblende deposit, very rich in radium, was discovered in Ferghana, in Russian Turkestan. Soviet Russia is now mining the ore and extracting the radium, which is kept at the Radium Institute of the Academy of Science.

Curiously enough, more than $500,000 worth of radium has been added to the world's store of this valuable element by "boiling down" British cannons used in the World War. No fewer than five grams—less than a tablespoonful—have been secured by British scientists by this process. The radium is stored in a lead safe weighing almost two tons—a container which was invented by a Dr. Kuss, and the composition of which is known only to himself. One of the greatest difficulties of scientists has been to find some material which would prevent the constant bombardment of the radium rays.

One important result of these recent discoveries—especially that of the Congo deposits—is that the price of radium dropped $30,000 a gram, and sells now at the rate of $70,000 a gram instead of some $100,000. The Standard Chemical Company of Denver, Colorado, has been obliged to close down its three-story laboratory, which until the close of the year 1922 had, for several years previously, been producing a million dollars' worth of radium annually. The Paradox Valley carnotite ore cannot be worked in competition with the rich deposits of the Belgian Congo. It has been stated that five pounds annually could be produced from these Congo deposits. The Colorado company had been selling at the rate of $58,500,000 a pound. The Congo company can profitably sell the precious element at $29,250,000 less a pound.

So, unless war breaks out again to prevent shipments from abroad, the United States of America will produce no more radium for a long while to come.

THE RADIOACTIVE DISINTEGRATION SERIES

In order to show the decomposition products of the two parent radioactive elements—Uranium and Thorium—and their chief characteristics, together with their relations to one another, and the time required for the product (element) to be half transformed, it is customary to arrange them in a *disintegration* *series.* There are three series, Uranium I, Uranium Y, and Thorium.

In the first table given below is shown how the series known as Uranium I is transformed into the end-product, uranium lead. This is followed by the Uranium Y (or Actinium) series, and by the Thorium series; the end-product of all three being a characteristic type of lead. In the tables T is the "time-period" of a product, or the time required for the product to be *half transformed.* In the column "Rays" is shown what type of ray, or rays, is, or are, emitted during the disintegration process—A=Alpha rays (or particles), B=Beta rays (negative electrons), and G=Gamma rays (or X-rays of very high "frequency").

"In the great majority of cases," says Sir Ernest Rutherford, "each of the radioactive elements breaks up in a definite way, giving rise to one Alpha or Beta particle and to one atom of the new product. Undoubted evidence, however, has been obtained that in a few cases the atoms break up in two or more distinct ways, giving rise to two or more products characterized by different radioactive properties. A branching of the uranium series was early demanded in order to account for the origin of Actinium."

In the first column is given the "atomic weight" of each radioactive element, the weight decreasing with (almost) every "disintegration period." The figures followed by an interrogation point are Rutherford's, and indicate that slightly different figures are given by other authorities.

URANIUM I SERIES

Element	Atomic Weight	T (average time-period—half transformed)	Rays (given out in each decomposition)
Uranium I	238	4.5×10^9 yrs.	Alpha
Uranium X1	234	23.8 days	Beta, Gamma
Uranium X2	234	1.15 min.	Beta, Gamma
Uranium II	234	About 2×10^6 yrs.	Alpha
Ionium	230	About 9×10^4 yrs.	Alpha
Radium	226	(+) 1700 yrs.	Alpha
Niton (Emanation)	222	3.85 days	Alpha
Radium A	218	3.05 min. (?)	Alpha
Radium B	214	26.8 min. (?)	Beta, Gamma
Radium C	214	19.5 min. (?)	Alpha, Beta, Gamma
Radium C′	214	10^{-6} sec. (?)	Alpha
Radium D	210	(+) 16 yrs.	Beta, Gamma
Radium E	210	(+) 4.85 days	Beta, Gamma
Radium F (Polonium)	210	(+) 136.5 days	Alpha
Radium G (End-product uranium-lead)	206	....	....

URANIUM Y (ACTINIUM) SERIES

Element	Atomic Weight	T (average time-period—half transformed)	Rays (given out in each decomposition)
Uranium Y (branching from Uranium II)	234	(+) 24.6 hrs. (2.2 days?)	Beta
Protoactinium	230	About 10^4 yrs. (?)	Alpha
Actinium	226	20 yrs.	Beta
Radio-actinium	226	19 days	Alpha
Actinium X	222	(+) 11.2 days	Alpha
Actinium (Emanation)	218	3.92 sec.	Alpha
Actinium A	214	.002 sec.	Alpha
Actinium B	210	36 min. (?)	Beta, Gamma
Actinium C	210	2.16 min. (?)	Alpha
Actinium D	206	4.76 min.	Beta, Gamma
Actinium E (End-product actinium-lead)	206	....	....

THORIUM SERIES

Element	Atomic Weight	T (average time-period—half transformed)	Rays (given out in each decomposition)
Thorium	232.1	2.2×10^{10} yrs.	Alpha
Mesothorium I	228	6.7 yrs.	Beta, Gamma
Mesothorium II	228	6.2 hrs. (?)	Beta, Gamma
Radio-thorium	228	1.90 yrs. (?)	Alpha
Thorium X	224	3.64 days	Alpha
Thorium (Emanation)	220	54 sec. (?)	Alpha
Thorium A	216	.14 sec. (?)	Alpha
Thorium B	216	10.6 hrs. (?)	Beta, Gamma
Thorium C	212	60 min. (?)	Alpha
Thorium D	208	3.2 min. (?)	Beta, Gamma
Thorium E (End-product thorium-lead)	208	....	....